4. MAJOR ACTIVITIES

The previous section outlined the science activities pursued in the Laboratory for Atmospheres. This section presents summary paragraphs of some of our major activities in measurements, field campaigns, data sets, data analysis, and modeling. In addition, we summarize the Laboratory's support for NOAA's remote sensing requirements. The section concludes with a listing of project scientists, and a description of interactions with other scientific groups.

4.1 Measurements

Studies of the atmosphere of Earth require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 4.1 shows the space missions that support scientific disciplines in the Laboratory. Satellites are shown in the left-most column. Instruments used by Laboratory scientists are listed in the Table under the supported disciplines in the first row. These instruments are those that were built in the Laboratory, for which a Laboratory scientist had responsibility as Instrument Scientist, for which Laboratory scientists were responsible for algorithm development, calibration and data analysis, or that provided data used by Laboratory scientists for model validation and development.

Table 4.1: Principal instruments supporting scientific disciplines in the Laboratory for Atmospheres.

Satellite	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
AIM	CIPS	SOFIE	CDE SOFIE
Aqua	AMSU AMSR-E HSB AIRS	AIRS	CERES AMSR-E AIRS MODIS
Aura	TES	OMI	MLS
Calipso			CPL
CloudSat			CRS
DSCOVR*	EPIC	EPIC	NISTAR EPIC
GOES	Sounder		Imager Sounder

GPM	DPR GMI		DPR GMI
NPP*	ATMS CrIS VIIRS	OMPS	VIIRS
POES			AVHRR
Terra		MOPITT	CERES MISR MODIS
ICESat			GLAS

* Planned mission, not yet launched

AIM: Aeronomy of Ice in the Mesosphere
AIRS: Atmospheric InfraRed Sounder
AMSR-E: Advanced Microwave Scanning Radiometer for EOS
AMSU: Advanced Microwave Sounding Unit
ATMS: Advanced Technology Microwave Sounder
AVHRR: Advanced Very High Resolution Radiometer
CDE: Cosmic Dust Experiment
CERES: Clouds and the Earth's Radiant Energy System
CIPS: Cloud Imaging and Particle Size experiment
CPL: Cloud Physics Lidar
CrIS: Cross-track Infrared Sounder
CRS: Cloud Radar System
DSCOVR: Deep Space Climate Observatory
DPR: Dual-frequency Precipitation Radar
EPIC: Earth Polychromatic Imaging Camera
GLAS: Geoscience Laser Altimeter System
GMI: GPM Microwave Imager
GOES: Geostationary Operational Environmental Satellite
GPM: Global Precipitation Measurement
HSB: Humidity Sounder for Brazil
ICEsat: Ice, Cloud, and land Elevation Satellite
MISR: Multi-angle Imaging SpectroRadiometer
MLS: Microwave Limb Sounder
MODIS: Moderate Resolution Imaging Spectroradiometer
MOPITT: Measurement of Pollution in the Troposphere
NISTAR: National Institute of Standards and Technology Advanced Radiometer
NPP: NPOESS Preparatory Project
NPOESS: National Polar Orbiting Environmental Satellite System
OMI: Ozone Monitoring Instrument
OMPS: Ozone Mapping and Profiler Suite
POES: Polar Orbiting Environmental Satellite
SOFIE: Solar Occultation for Ice Experiment
TES: Tropospheric Emission Spectrometer
VIIRS: Visible/Infrared Imager/Radiometer Suite

Table 4.2 lists instruments used in suborbital missions supporting scientific disciplines in the Laboratory. The left-most column indicates each instruments deployment.

Table 4.2: Instruments used in Suborbital Missions that Support Scientific Disciplines in the Laboratory for Atmospheres. (Acronyms not listed previously are listed below this table.)

Instrument Deployment	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
Aircraft/Balloon	EDOP HARLIE TWiLiTE (IIP) URAD HIWRAP (IIP)	AROTAL RASL (IIP) ACAM	CPL THOR Lidar CRS UAV CPL
Ground/Laboratory/ Development	SRL GLOW	STROZ LITE AT Lidar (ATL) Brewer UV Spectrometer KILT Pandora Spectrometers L2-SVIP GeoSpec (IIP)	MPL COVIR SMART COMMIT

ACAM	Airborne Compact Atmospheric Mapper
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ATL	Aerosol and Temperature Lidar
COMMIT	Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere
COVIR	Compact Visible and Infrared Radiometer
EDOP	ER-2 Doppler Radar
GeoSpec	Geostationary Spectrograph
GLAS	Geoscience Laser Altimeter System
GLOW	Goddard Lidar Observatory for Winds
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
IIP	Instrument Incubator Program
KILT	Kiritimati Island Lidar Trailer
L2-SVIP	Lagrange-2 Solar Viewing Interferometer Prototype
MPL	Micro-Pulse Lidar
RASL	Raman Airborne Spectroscopic Lidar
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SRL	Scanning Raman Lidar
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment

THOR	cloud THickness from Offbeam Returns
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UAV	Unmanned Aerial Vehicle
URAD:	Unmanned Aerial Vehicle Radar
UV	Ultraviolet

In most cases, details concerning the instruments listed in these tables are presented in a separate Laboratory technical publication, the Instrument Systems Report, NASA/TP-2005-212783, which is also available on the Laboratory's home page, http://atmospheres.gsfc.nasa.gov/.

4.2 Field Campaigns

Field campaigns use the resources of NASA, other agencies, and other countries to carry out scientific experiments, to validate satellite instruments, or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2, DC-8, and WB-57F serve as platforms from which remote sensing and *in situ* observations are made. Ground-based systems are also used for soundings, remote sensing, and other radiometric measurements. In 2007, Laboratory personnel supported six such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

Figure 4.1 Instrumentation at the SAUNA site.

4.2.1 SAUNA-II

Sodankylä, Finland, February–April

The objective of the Sodankylä Total Column Ozone Intercomparison (SAUNA) was to assess the comparative performance of ground-based instruments and algorithms at high latitudes. Total column ozone retrievals show persistent differences of 5–10% at high latitudes under conditions of low Sun, high total column ozone, and high column variability. Once the accuracy of the ground-based systems has been established under these extreme conditions, the accuracy of satellite retrievals can be assessed. For this purpose, the SAUNA campaign was held in Sodankylä, Finland (67°N, 23°E) in March–April of 2006, with a follow-up campaign (called SAUNA-II) in February–April 2007. SAUNA was supported as part of the Aura validation program.

Sodankylä was chosen for the campaign because a combination of high solar zenith angles and very high total ozone can be expected during mid-spring. During the campaign, Dobsons, Brewers, DOAS, sondes, and LIDAR were compared, including World and European standard instruments. The Goddard mobile ozone lidar system and double Brewer participated. The campaign involved more than 30 scientists from 12 institutes in 10 countries.

Initial results showed that the double spectrometer Brewer instruments were needed for accuracy at high ozone high solar zenith angles. The scattered light error in the Dobsons and single Brewers was documented. It was also shown that spatial variability in this region of high ozone gradients could be a significant source of inconsistency in satellite versus ground-based comparisons.

For further information contact Rich McPeters, Richard.D.McPeters@nasa.gov.

4.2.2 Cloud and Land Surface Interaction Campaign (CLASIC)

The Cloud and Land Surface Interaction Campaign (CLASIC) was sponsored by the Department of Energy's Atmospheric Radiation Program to study influences of land surface processes on cumulus convection. It was conducted at the ACRF Southern Great Plains (SGP) field measurement site during the summer of 2007. CLASIC was designated as the core of a 2007 priority for the interagency Water Cycle Working Group of the Climate Change Science Program (CCSP). CLASIC scientists collect data sets, both at the surface and from aircraft, which can be used to improve parameterizations of cumulus convection and associated parameterizations of land surface processes. The results will be used to help decipher the respective roles of local and regional forcing on the observed cloud structure and will lead to improved representation of cloud and land surface feedbacks in climate models.

NASA's involvement in this campaign during June 2007 was to provide the ER-2 aircraft for cloud remote sensing. The ER-2 flights were coordinated with other aircraft and were mainly conducted over the ARM Southern Great Plains site in Oklahoma. Low-flying aircraft measured atmospheric radiation and surface fluxes, while the high-altitude ER-2 aircraft provided remote sensing using the Cloud Physics Lidar (CPL, McGill/613.1), Cloud Radar System (CRS, Heymsfield/613.1), and the MODIS Airborne Simulator (MAS, King and Platnick) instruments. Because the ER-2 was flying an A-Train simulator payload, underflights of the CALIPSO and CloudSat satellites were also performed as part of CLASIC.

The MODIS Airborne Simulator (MAS), a high spatial resolution imaging spectrometer flown on the NASA ER-2, has the spectral coverage to allow for cloud retrievals using algorithms similar to those used to produce operational MODIS cloud products. For the CLASIC campaign, the existing MAS retrieval code was updated to use the latest Collection 5 MODIS algorithm, though some modifications were required and are still being investigated. The emphasis was on retrieval of boundary layer water cloud properties. For more information on MAS and its use in the CLASIC campaign, visit http://mas.arc.nasa.gov/data/deploy_html/clasic_home.html or contact Steve Platnick (steven.platnick@nasa.gov).

4.2.3 Tropical Composition, Cloud, and Climate Coupling (TC4)

The region of the Earth's tropical atmosphere between 14 and 18 km plays a key role in both climate change science and atmospheric ozone depletion. This layer, the tropical tropopause transition layer or TTL, is one of the coldest locations in the Earth's atmosphere. The TTL controls the inflow into the tropical stratosphere. Many facets of the chemical, dynamical, and physical processes occurring in the TTL are not well understood. Identifying and quantifying such processes are essential to understanding climate change, ozone depletion, and tropospheric chemistry. The TC4 campaign, conducted during July and August 2007, and based in San Jose, Costa Rica, explored this layer using seven NASA satellites and three NASA aircraft, and also obtained ground-based radar and balloon measurements from San Jose and a site in Panama. The campaign focused on understanding the composition of the TTL and analyzing the impact of the deep clouds that penetrate the atmosphere up into this layer. A special focus was the cirrus clouds produced by the deep convective clouds, and the subsequent life-cycle and chemistry associated with these extensive ice clouds. Convection was plentiful as the Intertropical Convergence Zone passes through this region during the summer.

A-Train satellite observations (Aura, Aqua, CloudSat and CALIPSO), and other satellite observations (Terra and TRMM), provided crucial information on the spatial and temporal variations within this region. Carefully planned TC4 aircraft observations were required, both to validate satellite data in this poorly know region and to provide critical observations not available from the satellites such as details of the ice cloud microphysical composition and measurements of various chemical tracer species, both short- and long-lived, in complex cloud environments.

Over 350 people from NASA, NOAA, NCAR, universities, Costa Rica, and Panama directly participated in TC4. NASA's high-altitude (20 km) ER-2 aircraft served as an A-Train satellite simulator, capable of sampling when and where needed. The ER-2 carried 11 instruments including the MODIS Airborne Simulator (MAS), Scanning HIS (AIRS and TES simulator), Goddard's Cloud Radar System (CRS—a CloudSat simulator), Goddard's Cloud Physics Lidar (CPL—a CALIPSO simulator) and Goddard's Compact Scanning Submillimeterwave Imaging Radiometer (CoSSIR). NASA's WB-57 served as an *in situ* sampling platform collecting cloud and aerosol particle measurements and a wealth of gas measurements from its 27 instruments, both inside clouds as well as in clear air at altitudes from 13–17 km, mostly in the TTL but occasionally extending into the lower stratosphere. NASA's DC-8 "Flying Laboratory" carried a complement of 26 instruments including upward and downward pointing lidars (ozone, water vapor, and aerosols) and radiometers as well as instruments for *in situ* measurements of gases, and cloud and aerosol particles. The DC-8 was key for Aura validation objectives as it was able to underfly the afternoon Aura overpass, which was not possible for the ER-2 or WB-57 because of typical afternoon weather conditions at the airfield. The DC-8 operated mostly below 13 km, and usually collected some data in the tropical boundary layer at altitudes less than 2 km during most missions. A total of 26 science flights were flown over the 23 days of TC4. The majority of these flights included highly coordinated observations with two or more aircraft. Because of a pre-mission mechanical malfunction of the aircraft, the WB-57 did not join the experiment until the final week during which operations were consequently very intensive.

The key TC4 science questions included:

1. How can space-based measurements of geophysical parameters, particularly those known to possess strong variations on small spatial scales (e.g., H_2O, cirrus), be validated in a meaningful fashion?

2. How do convective intensity and aerosol properties affect cirrus anvil properties?

3. How do cirrus anvils, and tropical cirrus in general, evolve over their life cycle? How do they impact the radiation budget and ultimately the circulation?

4. What controls the formation and distribution of thin cirrus in the TTL, and what is the influence of thin cirrus on radiative heating and cooling rates, and on vertical transport?

5. What are the physical mechanisms that control (and cause) long-term changes in the humidity of the upper troposphere in the tropics and subtropics?

6. What are the source regions, identities, concentrations, and chemical fates of short-lived compounds transported from the tropical boundary layer into the TTL. (i.e., what is the chemical boundary condition for the stratosphere?)

7. What are the mechanisms that control ozone within and below the TTL?

8. What mechanisms maintain the humidity of the stratosphere? What are the relative roles of large-scale transport and convective transport and how are these processes coupled?

Typical missions focused on cloud observations in the morning using multiple aircraft. The DC-8 subsequently took additional measurements more focused on chemistry issues and Aura validation in the early afternoon. For example, the mission on August 8 included observations of cloud profiles in cirrus anvils formed from deep convection rooted in a layer containing Saharan dust at lower levels, chemistry profiles of the TTL to obtain chemical tracers upwind of convection, and chemistry samples at low altitudes over dense tropical jungles in Columbia. Missions were also flown to sample the chemical and aerosol input to the deep convective clouds and to sample volcanic plumes over South America. Overall, the TC4 mission was a great success despite a number of logistical challenges, including recovery from a lightning strike on the DC-8, fuel issues for the ER-2, and the pre-mission WB-57 malfunction. The pilots, aircrews, ground crews, and support staff performed admirably under difficult circumstances to ensure mission success. The science findings spanning a diverse set of questions are much anticipated.

Laboratory scientists on the TC4 leadership team included David Starr (613.1)—Co-Mission Scientist; Steve Platnick (613.2) and Paul Newman (613.3)—ER-2 Platform Scientists; and Mark Schoeberl (610)—DC-8 Platform Scientist. Joanna Joiner (613.3) and Anne Douglass (613.3) represented Aura validation interests, and Steve Platnick served a similar role for MODIS (Aqua and Terra). ER-2 instrument scientists included Michael King (610)—MAS/MASTER; Gerry Heymsfield (613.1)—CRS and EDOP; Matt McGill (613.1)—CPL; and Jim Wang (614.6)—CoSSIR. Gerry Heymsfield also contributed to the success of the DC-8 dropsonde experiment that was operated in the field by personnel from NASA HQ.

A unique aspect of TC4 was the use of a Google Earth application developed at NASA Marshall Space Flight Center to direct the aircraft in real time via Satphone-Internet connections. Additional information about TC4 may be found at http://www.espo.nasa.gov/tc4/. TC4 observations and images for various Goddard instruments can be found on the respective instrument Web sites at Goddard.

4.2.4 The Water Vapor Validation Experiment-Satellite/Sondes 2007 (WAVES_2007)

Howard University Research Campus, Beltsville, MD, July 14–August 8

The WAVES_2007 campaign took place in July 2007 and was centered at the Howard University Research Campus in Beltsville, Maryland. The goals, similar to those of WAVES_2006, which occurred in June–August 2006, were to provide a large, robust data set for comparison with and validation of Aura and Aqua satellite measurements of ozone, temperature, and water vapor; to intercompare and validate Raman water vapor lidar measurements; and to improve the summertime water vapor/ozone climatology in a highly populated suburban region near the nation's capitol. The measurement systems used during WAVES_2007 included many of those in use in WAVES_2006: Vaisala RS92 radiosonde, ECC ozonesonde, Cryogenic Frostpoint Hygrometer (provided by the University of Colorado), and operational radiosonde packages provided by the National Weather Service; and the large suite of atmospheric sensing instruments located at the Howard University facility (http://meiyu.atmphys.howard.edu/beltsville/inde3.html). Two lidar systems from GSFC were used along with others from Howard University (HURL Raman Lidar), and UMBC (ALEX Raman lidar and ELF backscatter lidar). The two NASA GSFC lidar assets that participated were the Code 613.3 AT Raman Lidar system and the Code 613.1 RASL (Raman Airborne Spectroscopic Lidar), which was involved in its first flight tests sponsored by the NASA Instrument Incubator and the GSFC ESTO programs. RASL flew legs along satellite tracks and overflew the Beltsville and UMBC sites permitting comparisons of water vapor and aerosol profiles with the other instruments. An example comparison of RASL, HURL and Vaisala RS92 radiosonde water vapor profiles from one of the RASL overpasses of the Beltsville site is shown in Figure 4.2. The 10 second resolution of the RASL data corresponds to approximately 1 km horizontal resolution. For further details please contact Dave Whiteman (David.N.Whiteman@nasa.gov) or Tom McGee (Thomas.J.McGee@nasa.gov).

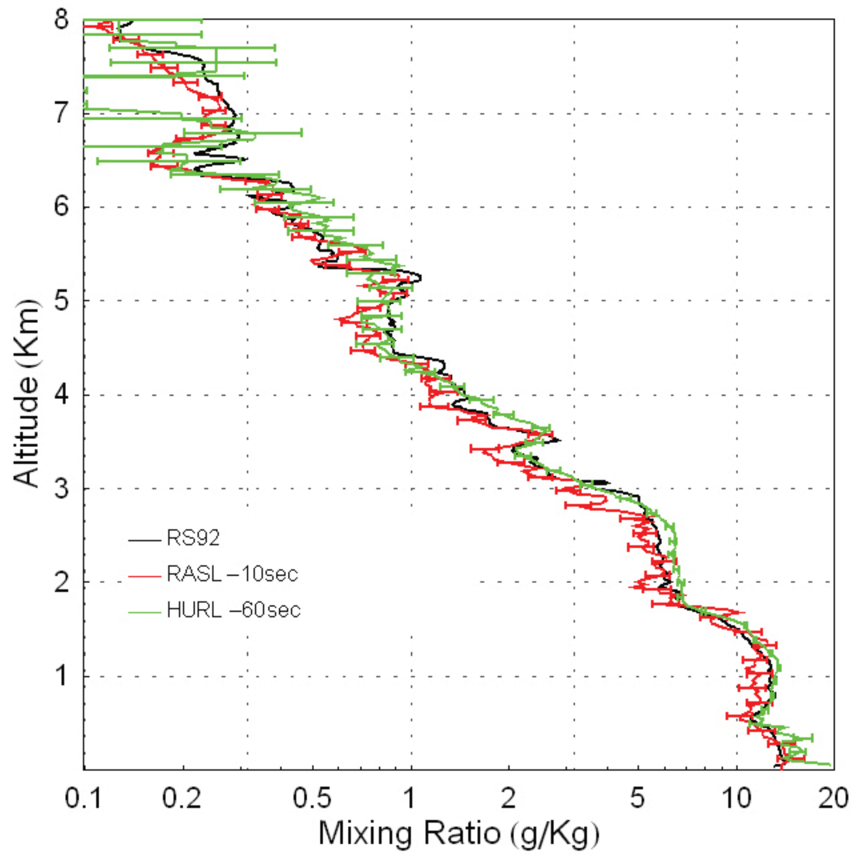


Figure 4.2 Example comparison of RASL, HURL, and Vaisala RS92 radiosonde water vapor profiles from one of the RASL overpasses of the Beltsville site.

4.2.5 Measurements of Humidity in the Atmosphere—Validation Experiments II (MOHAVE II)

October 4–17, 2007, JPL Table Mountain Facility, CA.

The Code 613.3 Aerosol, Temperature and Water Vapor (AT) Lidar, as well as the Code 613.1 ALVICE (Atmospheric Lidar for Validation, Interagency Collaboration and Education) Raman lidar were used in the second MOHAVE campaign at JPL's Table Mountain Facility in Southern California in October 2007. The campaign consisted of these two GSFC lidars, the JPL Water Vapor Lidar (all co-located at TMF) and numerous balloon sonde sensors.

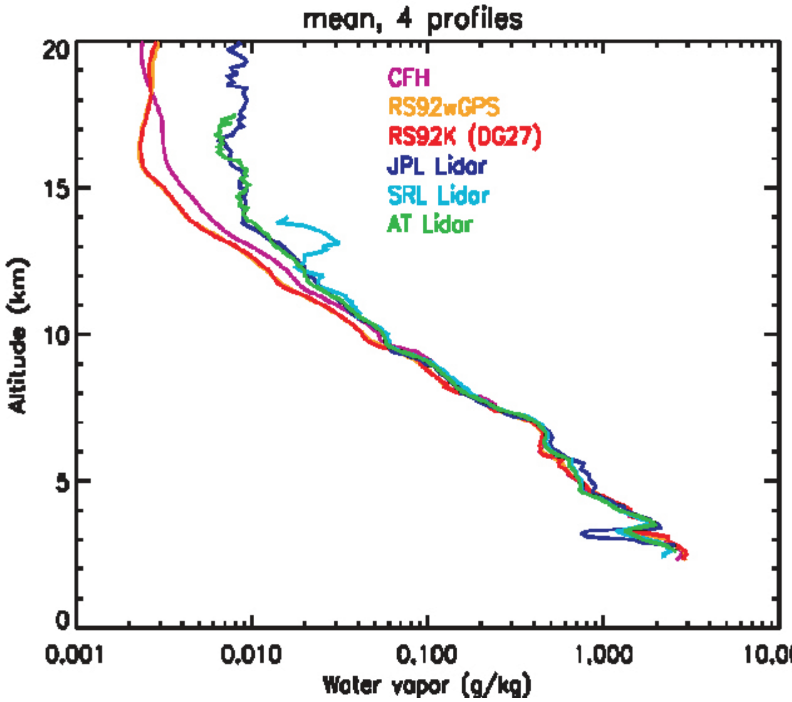


Figure 4.3 MOHAVE-I water vapor comparisons.

During the first MOHAVE-I campaign, which occurred in October of 2006 and also at TMF, it was noted that all of the lidars had a bias with respect to the sonde instruments at low water vapor concentrations (see Figure 4.3). This wet bias was presumed to be due to fluorescence from internal optical components of the lidar instruments. This was the major finding from the first campaign, and the second campaign was conducted to determine if the proposed solutions to the interference were successful and if high power-aperture Raman lidars, when located at a high altitude station (2385 m MSL) such as TMF, are able to accurately quantify water vapor to the tropopause and beyond. Preliminary data indicates that the lidar water retrievals are improved at high altitudes and the data are currently being analyzed in detail. For further details please contact Tom McGee (Thomas.J.McGee@nasa.gov) or Dave Whiteman (David.N.Whiteman@nasa.gov).

4.2.6 Measurement of NO_2

New compact low-cost (~$10K) solar-viewing spectrometers (PANDORA) have been developed at GSFC to measure aerosols, NO_2, and other trace gases in the atmosphere (H_2O, HCHO, O_3, SO_2). The goal in developing these new spectrometer instruments was to be able to deploy them at multiple sites for detection of atmospheric pollution and to validate Aura/OMI satellite data. Before deploying large numbers of these systems, two field campaigns at GSFC and JPL's Table Mountain Facility (TMF) were designed to validate their performance against a larger more expensive system, MF-DOAS, developed by George Mount of Washington State University. Two versions of the PANDORA spectrometers have been developed, one to only make direct sun observations, PAN-1, and the other to measure both direct sun and diffuse sky radiances, PAN-3.

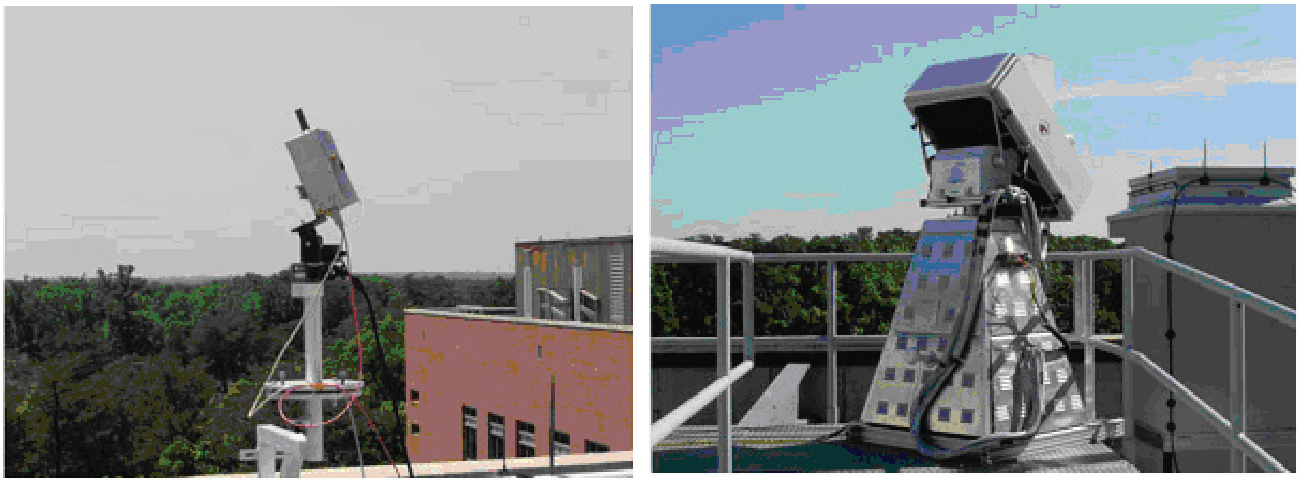


Figure 4.4 PAN-1 and the University of Washington MF-DOAS mounted on the roof at GSFC in May 2007. As shown, PAN-1 only observes the direct Sun, while MF-DOAS can observe both the direct Sun and diffuse sky radiances.

The first set of field measurements was obtained at GSFC (38.993°N, 76.840°W) during a comparison campaign of PAN-1 with the University of Washington's MF-DOAS instrument located on the roof of Building 33, about 88 m above sea level with a view of the horizon in most directions. A picture of both instruments is shown in Figure 4.4. The GSFC location is close to two major highway systems and a busy local road, which are strong sources of NO_2 emissions. In addition, aerosols are almost always present with a typical optical depth of a few tenths.

The second campaign was held in late June 2007 at JPL's Table Mountain Facility (34.382°N, 117.681°W) which is an extremely clean site even though it is fairly near Los Angeles, California. Once again, PAN-1 and MF-DOAS were located on the same rooftop (Figure 4.5) approximately 2.2 km above sea level with a view of the horizon to the east, but with other directions partly obscured by terrain, structures, or trees.

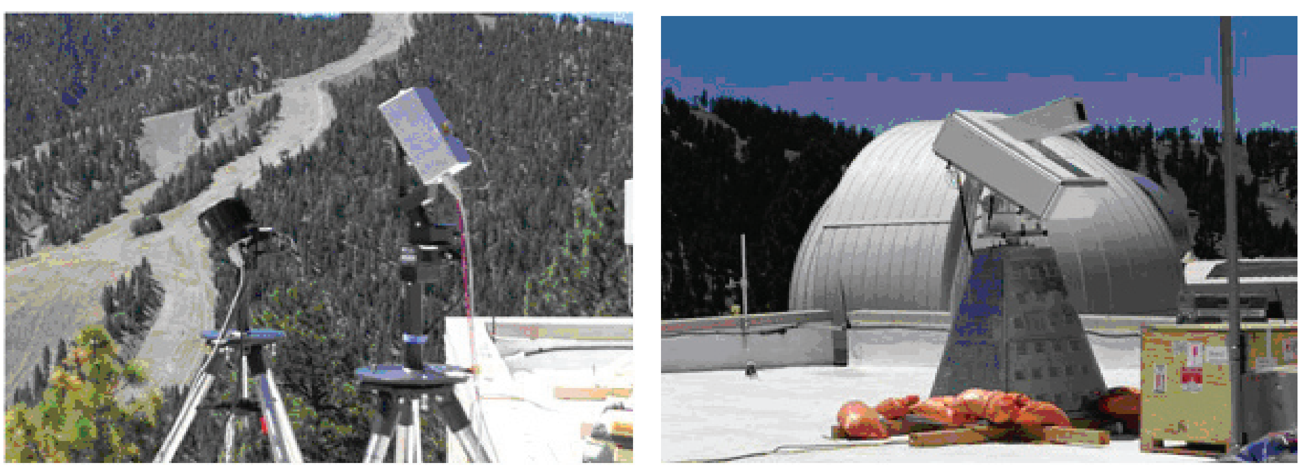


Figure 4.5 PAN-1, PAN-3, and MF-DOAS at Table Mountain Facility California July 2, 2007. The view is looking to the north.

The results from the two campaigns are summarized in Figures 4.6 and 4.7, which compare the measured slant columns of NO_2 obtained by the two instruments. The campaign at GSFC was designed to compare PAN-1 with similar measurements made by the University of Washington's MF-DOAS spectrometer in a moderately polluted area. A similar comparison was made at the very clean Table Mountain Facility in California where the expected total column NO_2 values do not differ much from the stratospheric NO_2 amount. When combined with the GSFC campaign, the data demonstrates the performance of both spectrometer systems for sites with low and substantial amounts of NO_2. The differences between the instruments are not statistically significant and range from 0.4% at low values of NO_2 to about 1% at higher values.

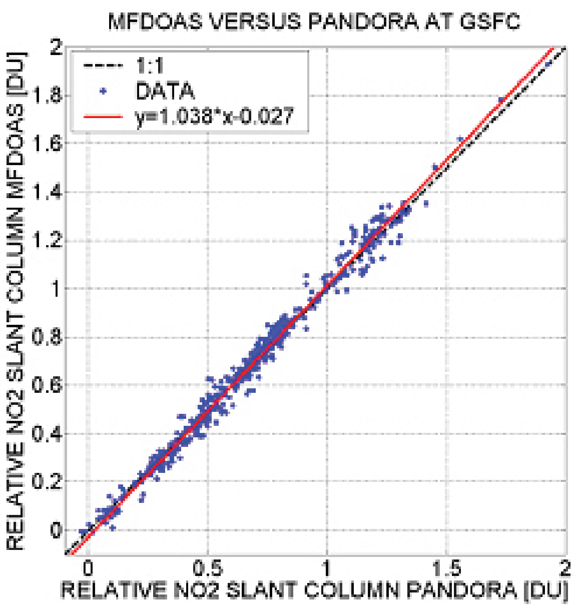


Figure 4.6 A comparison of PAN-1 and MF-DOAS at GSFC (May 2007).

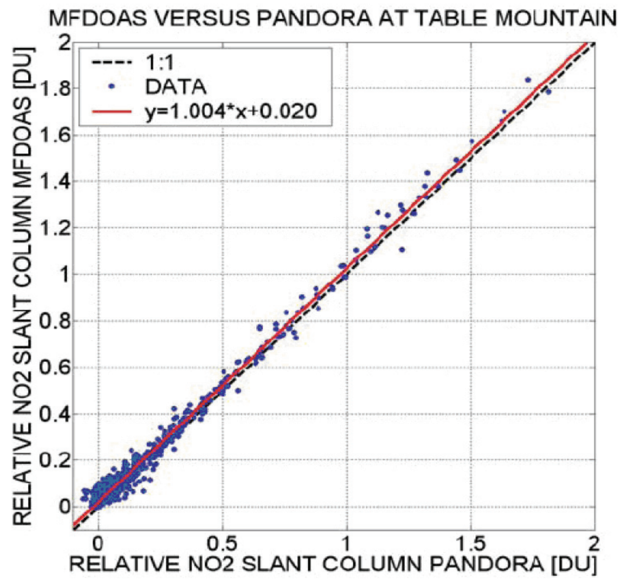


Figure 4.7 A comparison of PAN-1 and MF-DOAS at TMF (July 2007).

Now that the PANDORA results have been validated in two field campaigns, multiple copies are being made to deploy within the Washington metropolitan area to map out the distribution of NO_2 and other trace gases. Instruments will be located at GSFC, NASA Headquarters, the Smithsonian Environmental Research Center on the Chesapeake Bay, and other locations. In addition, instruments will be located at remote sites such as Houston, Atlanta, and Los Angeles to measure pollution levels and to validate corresponding OMI measurements. For further details contact Jay Herman, (Jay.R.Herman@nasa.gov).

4.3 Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns are used directly in scientific studies. Some of this data, plus data from additional sources, is arranged into data sets useful for studying various atmospheric phenomena. Some major data sets are described in the following paragraphs.

4.3.1 Global Precipitation

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing climatic fluctuations and trends on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) has established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory are leading the GPCP effort to merge data from both low-Earth orbit satellites and geosynchronous satellites, and ground-based rain gauges, to produce research-quality estimates of global precipitation.

The GPCP data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at NOAA's National Climatic Data Center in Asheville, North Carolina, and at the Goddard Earth Sciences Data and Information Services Center (GES DISC). Evaluation is ongoing for this long-term data set in the context of climatology, El Niño Southern Oscillation (ENSO)-related variations, and regional and global trends. The 10-year TRMM data set is being used in the assessment of the longer GPCP data set. A daily, globally complete analysis of precipitation is also being produced by Laboratory scientists for GPCP for the period 1997 to the present and is available from the archives.

An even finer time resolution, a TRMM-based quasi-global, 3-hour resolution rainfall analysis, the TRMM Multi-satellite Precipitation Analysis (TMPA) is available from the GES DISC for the period of January 1998 to the present. This product uses TRMM data to calibrate or adjust rainfall estimates from other satellite data and combines these estimates into rainfall maps at a frequency of every 3 hours at a spatial resolution of 0.25° latitude-longitude. A real-time version of this analysis is available through the TRMM Web site. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.3.2 Merged TOMS/SBUV Data Set

We have updated our merged satellite total ozone data set through May of 2007. We have transferred the calibration from the original six satellite instruments to the NOAA 16 and NOAA 17 SBUV/2 instruments. We have further extended this intercalibration to include the OMI instrument on the Aura satellite. We also have a merged profile data set from the SBUV instruments. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov).

4.3.3 Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS operational Atmosphere Team algorithms produce both Level-2 (pixel-level or swath data) and Level-3 (gridded) products. There are six categories of Level-2 and Level-3 MODIS products collected from the Terra and Aqua platforms. Over the past year, the latest processing stream (referred to as "Collection 5") was completed. In addition, a new algorithm designed to retrieve aerosols over desert surfaces was added in collection 5.

The Level-2 product files are grouped by Cloud Mask, Cloud, Aerosol, Precipitable Water, and Atmospheric Profile geophysical retrievals. In addition, a joint Atmosphere Team file contains a spatial sample of the more popular Level-2 retrievals. Level-3 MODIS Atmosphere products provide statistics on a 1° × 1° global grid and are produced for daily, eight-day, and monthly time periods.

Level-2 Products

The **Aerosol Product** provides aerosol optical thickness over the oceans globally and over a portion of the continents. Further, information regarding the aerosol size distribution is derived over the oceans, while the aerosol type is derived over continents. A new aerosol algorithm for bright desert surfaces (referred to as the “Deep Blue” algorithm) was included in the Aqua MODIS collection 5 processing; this algorithm provides aerosol optical depth as well as single scattering albedo for dust aerosol. Level-2 aerosol retrievals are at the spatial resolution of a 10×10, 1 km (at nadir) pixel array.

The **Precipitable Water Product** consists of two-column water vapor retrievals. During the daytime, a near-infrared algorithm is applied over clear land areas, ocean sun glint areas, and above clouds over both land and ocean. An infrared algorithm used in deriving atmospheric profiles is also applied both day and night.

The **Cloud Product** combines infrared and visible techniques to determine both physical and radiative cloud properties. Cloud optical thickness, effective particle radius, and water path are derived at a 1 km resolution using MODIS visible through mid-wave infrared channel observations. Cloud-top temperature, pressure, and effective emissivity are produced by infrared retrieval methods, both day and night, at a 5×5, 1 km pixel resolution. Cloud thermodynamic phase is derived from a combination of techniques and spectral bands. Finally, the MODIS Cloud Product includes an estimate of cirrus reflectance in the visible at a 1 km pixel resolution; these retrievals are useful for removing cirrus scattering effects from the land-surface reflectance product.

The **Atmospheric Profile Product** consists of several parameters: total column ozone, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. All of these parameters are produced day and night at a 5×5, 1 km pixel resolution when a 5×5 region is suitably cloud free.

The **Cloud Mask Product** indicates to what extent a given instrument field of view (FOV) of the Earth’s surface is unobstructed by clouds. The cloud mask also provides additional information about the FOV, including the presence of cirrus clouds, ice/snow, and sun glint contamination.

The **Joint Atmosphere Product** contains a subset of key parameters gleaned from the complete set of operational Level-2 products: Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask. The Joint Atmosphere product was designed to be small enough to minimize data transfer and storage requirements, yet robust enough to be useful to a significant number of MODIS data users. Scientific data sets (SDSs) contained within the Joint Atmosphere Product cover a full set of high-interest parameters produced by the MODIS Atmosphere Group, and are stored at 5 km and 10 km (at nadir) spatial resolutions.

Level-3 Products

The Level-3 MODIS **Atmosphere Daily Global Product** contains roughly 600 statistical data sets, which are derived from approximately 80 scientific parameters from four Level-2 MODIS Atmosphere Products: Aerosol, Water Vapor, Cloud, and Atmospheric Profile. Statistics are sorted into $1° \times 1°$ cells on an equal-angle grid that spans 24 hours (0000 to 2400 UTC). A range of statistical quantities is computed, depending on the parameter being considered. In addition to simple statistics, the Level-3 files include a variety of one- and two-dimensional histograms. Similarly, the Level-3 Eight-Day and Monthly Global Product contain roughly 800 statistical data sets that are derived from the Level-3 Daily and Eight-Day products, respectively. For further information, contact Steven Platnick (Steven.Platnick@nasa.gov) or visit the MODIS Web site at http://modis-atmos.gsfc.nasa.gov/

4.3.4 MPLNET Data Sets

The NASA Micro Pulse Lidar Network (MPLNET) is a federated network of Micro Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods required to contribute to climate change studies and to provide ground validation for models and satellite sensors in the NASA Earth Observing System (EOS). At present, there are fourteen permanent sites worldwide, and four more are to be completed soon (Figure 4.8). Numerous temporary sites have been deployed in support of various field campaigns since the start of MPLNET in 2000, and three more are planned in 2008. Most MPLNET sites are co-located with sites in the NASA Aerosol Robotic Network (AERONET) to provide both column and vertically resolved aerosol and cloud data.

In addition to continuation of expansive network growth during 2007, MPLNET data have been reprocessed using a new data release, version 2. Version 2 data include many new data products. Scene classification is now provided continuously at 1 minute time resolution, including identification of multiple cloud layer heights (base and top), planetary boundary layer height, and the height of the highest aerosol layer. Existing aerosol products have been enhanced to include continuous aerosol extinction profiles and associated products throughout the day (previously only available at AERONET observation times). PBL heights are generated using a wavelet technique. Cloud products are currently under development. The optical depth of detected cloud layers will be provided to the limit of detection capability, including thick cloud optical depths up to 100 using a novel technique based on the lidar background signal. Further information on the MPLNET project, and access to data, may be obtained online at http://mplnet.gsfc.nasa.gov. For questions on the MPLNET project, contact Judd Welton (Judd.Welton@nasa.gov).

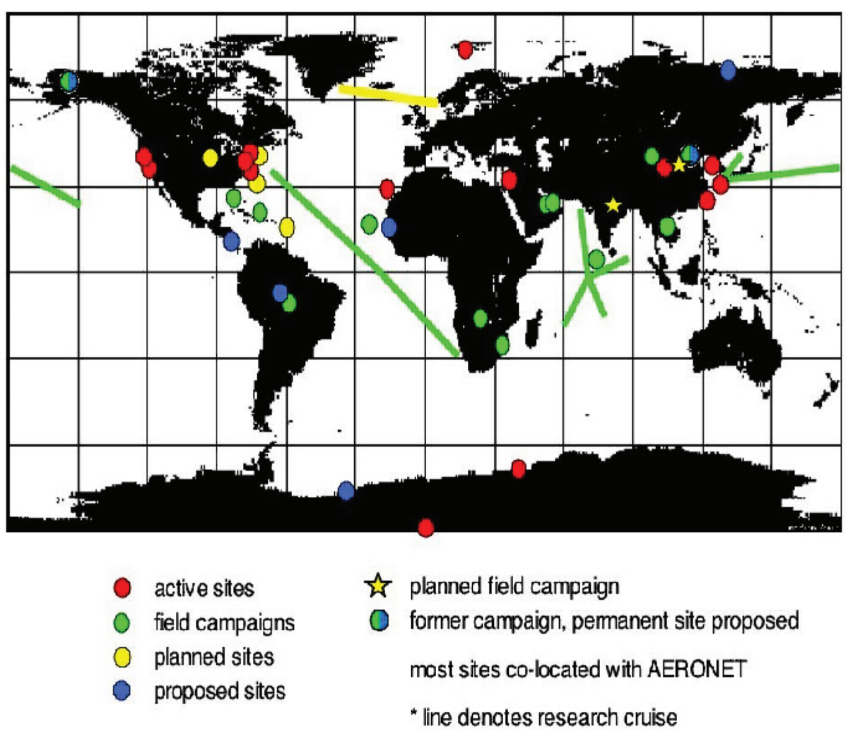


Figure 4.8 MPLNET Sites as of December 2007

4.3.5 TIROS Operational Vertical Sounder (TOVS) Pathfinder

The Pathfinder Projects are joint NOAA–NASA efforts to produce multiyear climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is TOVS. TOVS is composed of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 until April 2005, when NOAA 14 stopped transmitting data. We used an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2004 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount, cloud height, Outgoing Longwave Radiation (OLR), clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, and NOAA 6, 7, 8, 9, 10, 11, 12, and 14. We have demonstrated with the 25-year TOVS Pathfinder Path A data set that TOVS data can be used to study interannual variability, trends of surface and atmospheric temperatures, humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data are being incorporated in the monthly and daily GPCP precipitation data sets.

We have also developed the methodology used by the AIRS science team to generate products from AIRS for weather and climate studies, and continue to improve the AIRS science team retrieval algorithm. A new improved algorithm, AIRS Science Team algorithm Version 5.0, is now operational at the GES DISC. The GES DISC has been producing AIRS level-2 soundings beginning September 2002 using Version 5 of the AIRS science team retrieval algorithm. Version 5 level 3 gridded products should be up to date early in 2008 and be generally available for climate studies by the scientific community. All products obtained in the TOVS Pathfinder data set are also produced from AIRS. The AIRS products are of higher quality than those of TOVS, but have been shown to be compatible in the anomaly sense. AIRS products can be used to extend the TOVS 25 year climate data set for longer term climate studies.

In joint work with Robert Atlas, Version 5.0 AIRS temperature profiles derived using this improved retrieval algorithm have been assimilated into the Laboratory forecast analysis system and have shown a significant improvement in weather prediction skill. Forecast results assimilating quality controlled temperature soundings were shown to be superior to those obtained assimilating AIRS radiances, as done operationally at NCEP and ECMWF (Joel.Susskind-1@nasa.gov).

4.3.6 TOMS and OMI Data Sets

Since the Atmospheric Chemistry and Dynamics Branch first formed, it has been tasked with making periodic ozone assessments. Through the years the Branch has led the science community in conducting ozone research by making measurements, analyzing data, and modeling the chemistry and transport of trace gases that control the behavior of ozone. This work has resulted in a number of ozone and related data sets based on the TOMS instrument. The first TOMS instrument flew onboard the Nimbus-7 spacecraft and produced data for the period from November 1978 through May 6, 1993 when the instrument failed. Data are also available from the Meteor-3 TOMS instrument (August 1991–December 1994) and from the TOMS flying on the Earth Probe (EP-TOMS) spacecraft (July 1996–present).

TOMS data are given as daily files of ozone, reflectivity, aerosol index, and erythemal UV flux at the ground. A new Version 8 algorithm was released in 2004, which addresses errors associated with extreme viewing conditions. These data sets are described on the Atmospheric Chemistry and Dynamics Branch Web site, which is linked to the Laboratory Web site, http://atmospheres.gsfc.nasa.gov/. Click on the "Code 613.3" Branch site, and then click on "Data Services." The TOMS spacecraft and data sets are then found by clicking on "TOMS Total Ozone data." Alternatively, TOMS data can be accessed directly from http://toms.gsfc.nasa.gov.

Very similar data are being produced by the OMI instrument on the recently launched Aura spacecraft and are also available from the TOMS Web site http://toms.gsfc.nasa.gov. Because of calibration problems with the aging EP-TOMS instrument, OMI data should be used in preference to TOMS data beginning in 2005. The following sections describe two of the recently developed OMI data sets. For more information, contact Rich McPeters, Richard.D.McPeters@nasa.gov.

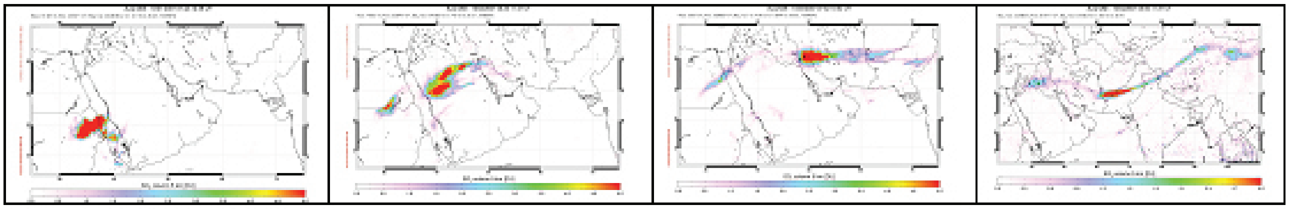
4.3.6.1 Sulfur Dioxide, SO_2

Sulfur dioxide (SO_2) is a short-lived atmospheric constituent that is produced primarily by volcanoes, power plants, refinery emissions and burning of fossil fuels. It can be a noxious pollutant or a major player in global climate forcing, depending on altitude. Fossil fuel burning occurs at the surface where SO_2 is released in the boundary layer or, with tall smokestacks, into the lower troposphere. Where SO_2 remains near the Earth's surface, it has detrimental health and acidifying effects. Emitted SO_2 is soon converted to sulfate aerosol by reaction with OH in air or by reaction with H_2O_2 in aqueous solutions (clouds). The mean lifetime varies from ~1–2 days or less near the surface to more than a month in the stratosphere. In the free troposphere, wind speeds are stronger and aerosol sulfate can be carried to remote regions where it can change radiative forcing directly as well as through altered cloud microphysics. The concentration of SO_2, the meteorological mechanisms that loft it above the PBL, and the efficiency of those mechanisms remain major unanswered questions in global atmospheric chemistry and climate science.

The first quantitative data on the mass of SO_2 in a major eruption (El Chichón, 1982) was obtained from the six-UV band NASA Nimbus-7 Total Ozone Mapping Spectrometer (TOMS). All significant eruptions since 1978 have now been measured by the series of TOMS instruments (Nimbus-7, Meteor-3, ADEOS I, Earth Probe (EP): http://toms.umbc.edu. The SO_2 detection sensitivity was limited to large volcanic clouds by the discrete TOMS wavelengths that were designed for total ozone measurements.

The Ozone Monitoring Instrument (OMI), launched in July 2004 on the polar-orbiting EOS/Aura satellite, offers unprecedented spatial and spectral resolution, coupled with global contiguous coverage, for space-based UV measurements of SO_2. The OMI SO_2 data set is continuing the TOMS record (e.g. http://toms.umbc.edu) but the improved sensitivity and smaller footprint of OMI have extended the range of detection to smaller eruptions, degassing volcanoes, and older clouds, and to anthropogenic pollution (http://so2.umbc.edu/omi/). Heavy anthropogenic emissions and volcanic degassing in the lower troposphere and boundary layer can be detected on a daily basis (e.g., http://aura.gsfc.nasa.gov; http://aura.gsfc.nasa.gov/science/gallery-omi.html; and http://www.knmi.nl/omi/research/news/). Using monthly or annual average SO_2 maps, one can detect weaker degassing and pollution, e.g., http://aura.gsfc.nasa.gov/science/top10_smelters.html).

Visualization of daily OMI SO_2 data allows rapid appraisal of the most significant volcanic SO_2 emitters, which in 2007 included Tungurahua and Reventador (Ecuador), Popocatépetl (Mexico), Sheveluch (Shiveluch, Kamchatka, Russia), Piton de la Fournaise, (Réunion) Nyiragongo (Democratic Republic of Congo), Manda Hararo (Afar, Ethiopia), Mt. Etna (Sicily, Italy) and Jebel al-Tair (Yemen). These measurements highlight the deficiencies of previous compilations of volcanic SO_2 emissions, which were biased towards accessible, frequently monitored volcanoes. The eruption of Jebel al-Tair (Yemen) volcano in the Red Sea on October 1, 2007 was the first since 1883 and produced an SO_2 cloud that was carried a long distance by the subtropical jet stream (Figure 4.9).



October 1 October 2 October 3 October 4

Figure 4.9 Long-range transport of the Jebel al-Tair volcanic SO_2 cloud by the subtropical jet stream observed by Aura/OMI instrument. on October 1–11, 2007 [*http://so2.umbc.edu/omi/*].

Using OMI data, one can directly compare daily global SO_2 emissions from anthropogenic and volcanic sources for the first time, and thus provide important new constraints on the relative magnitude of these fluxes. Anthropogenic SO_2 has been detected over eastern China, South America and Europe. An OMI SO_2 validation study was conducted using aircraft *in situ* SO_2 data collected over Shenyang in northeast China as part of the EAST-AIRE field campaign. (Figure 4.10).

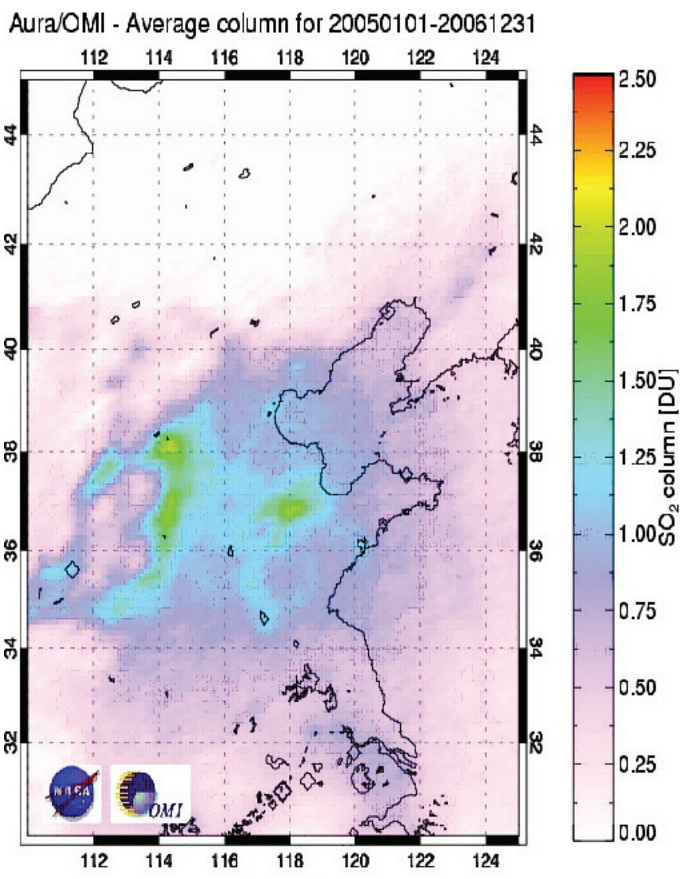


Figure 4.10 A 2-year average OMI SO_2 map over Eastern China in Dobson Units (1 DU=2.69 × 10^{16} molecules/cm^2) showing persistent areas of high SO_2 concentrations in a triangle between Beijing, Shanghai, and the Sichuan basin in agreement with emission inventories. Smaller SO_2 enhancements (~0.5 DU) over the Shenyang region in North East China (black square) are also significant as compared to the background regions. This was the place of the first OMI SO_2 validation study.

Such measurements are essential given the growing concern over the response of the Earth to anthropogenically-forced climate change and intercontinental transport of air pollution. Becasue SO_2 is the major precursor of sulfate aerosol, which has climate and air quality impact, OMI SO_2 measurements will contribute to better understanding of the sulfate aerosol distribution and its atmospheric impact. The fast OMI SO_2 retrieval is also amenable to operational SO_2 alarm development, and near real-time application for aviation hazards and volcanic eruption warnings. For more information contact Nick Krotkov (Nickolay.A.Krotkov@ nasa.gov).

4.3.6.2 Cloud

The OMI cloud algorithm retrieves cloud pressures from the filling in of solar Fraunhofer lines in the ultraviolet due to rotational Raman scattering of air molecules. Clouds shield the atmosphere below them from rotational Raman scattering as observed from a satellite above. Therefore, the higher the cloud, the less filling in that is observed. When there are multiple cloud decks and the upper deck is relatively thin, the retrieved cloud pressure is closer to the pressure of the lower cloud deck. In contrast, cloud pressures derived from thermal infrared sensors such as on the MODIS instrument are closer to the upper cloud deck. The cloud pressures derived from OMI are appropriate for use in retrievals of trace gases, such as ozone, NO_2, and SO_2, that utilize similar spectral regions. Over the past year, the OMI Raman cloud group has assessed potential errors in the algorithm using radiative transfer calculations. They also performed validation of the cloud pressure product using data from the recently launched CloudSat cloud profiling radar.

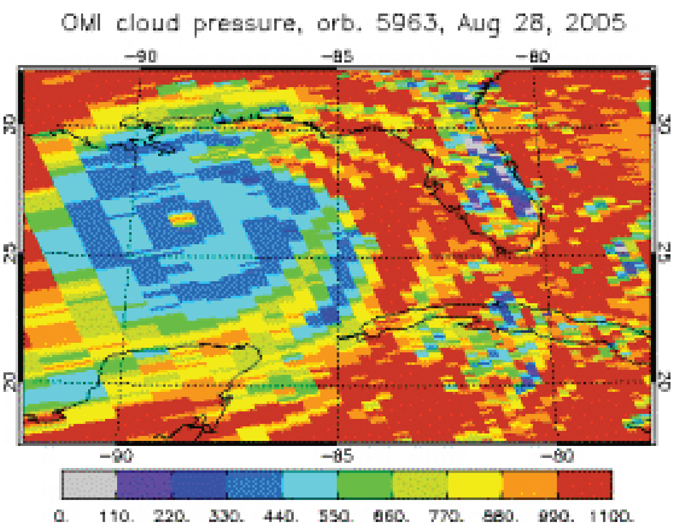


Figure 4.11 OMI cloud image over Hurricane Katrina, Aug. 28, 2005. The colors represent effective pressure of clouds, in hPa, as seen by OMI.

For more information contact Joanna Joiner (Joanna.Joiner@nasa.gov).

4.3.7 Southern Hemisphere ADditional OZonesondes (SHADOZ)

Initiated by NASA's Goddard Space Flight Center in 1998, in collaboration with NOAA and meteorological and space agencies from around the world, SHADOZ augments balloon-borne ozonesonde launches in the tropics and subtropics. SHADOZ presently includes 12 operational sites, including 3 that are north of the equator (Costa Rica, Suriname, and Malaysia). Each station launches weekly or monthly, depending on the resources available. SHADOZ archives ozone and temperature profile data at a user-friendly, open Web site: http://croc.gsfc.nasa.gov/shadoz. The year 2008 will mark 10 years of operations. SHADOZ ozone data are used for a number of purposes:

(1) Satellite algorithm retrievals and validation of satellite measurements,

(2) Mechanistic studies of processes affecting ozone distributions in the tropical stratosphere and troposphere, and

(3) Evaluation of photochemical and dynamical models that simulate ozone.

By having so many profiles, it has been possible to improve accuracy and precision of the ozonesonde measurement under tropical conditions. All SHADOZ stations fly a radiosonde Electrochemical Concentration Cell (ECC) ozonesonde combination. The World Meteorological Organization (WMO) uses SHADOZ as the paradigm for developing new ozone sounding stations in WMO's Global Atmospheric Watch (GAW) program.

Figure 4.12 Currently, twelve active sites are participating in SHADOZ. The sites are at Ascension Island; American Samoa; Fiji; Irene, South Africa; Watukosek, Java, Indonesia; Nairobi, Kenya; Alajuela, Costa Rica; Natal, Brazil; Paramaribo, Surinam; La Réunion; San Cristóbal, Galapagos; and Kuala Lumpur, Malaysia.

For additional details, contact Anne Thompson (anne@met.psu.edu) or Jacquie Witte (Jacquelyn.C.Witte@nasa.gov). The archive URL is located at http://croc.gsfc.nasa.gov/shadoz.

4.3.8 Tropospheric O_3 Data

Measurements from the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) on board the Aura satellite have been used to develop several years of daily and monthly-mean global measurements of tropospheric O_3 beginning late August 2004. The tropospheric O_3 data are given as both tropospheric column O_3 (in Dobson Units) and mean equivalent volume mixing ratio (in ppbv). The tropospheric O_3 data are made available to anyone via the TOMS home page http://toms.gsfc.nasa.gov. The Web site also provides long time records of both tropospheric and stratospheric O_3 in the tropics for the time period January 1979 through December 2005. For more information, contact Jerry Ziemke (Jerald.R.Ziemke@nasa.gov) the Principal Investigator on the American OMI science team for tropospheric ozone.

4.4 Data Analysis

A considerable effort by our scientists is spent in analyzing the data from a vast array of instruments and field campaigns. This section details some of the major activities in this endeavor.

4.4.1 Aerosol and Water Cycle Dynamics

Aerosol can influence the regional and global water cycles by changing the surface energy balance, modifying cloud microphysics, and altering cloud and rainfall patterns. On the other hand, condensation heating from rainfall, and radiative heating from clouds and water vapor associated with fluctuations of the water cycle, drive circulation, which determines the residence time and transport of aerosols and their interaction with the water cycle. Understanding the mechanisms and dynamics of aerosol-cloud-precipitation interaction, and eventually implementing realistic aerosol-cloud microphysics in climate models are clearly important pathways to improve the reliability of predictions by climate and Earth system models. Laboratory scientists are involved in analyses of the interrelationships among satellite-derived quantities such as cloud optical properties, effective cloud radii, aerosol optical thickness (MODIS, TOMS, CloudSat, and CALIPSO), rainfall, water vapor, and cloud liquid water (TRMM, AMSR), in conjunction with analyzed large scale circulation and estimated moisture convergence in different climatic regions of the world, including the semi-arid regions of southwest U.S., the Middle East, northern Africa, and central and western Asia. Field campaigns for measurement of aerosol properties, including ground-based and aircraft measurement, play an important role in this research.

Observations from satellite and field campaigns are being coordinated with numerical studies using global and regional climate models and cloud-resolving models coupled to land surface, vegetation, and ocean models. A major goal of this research activity is to develop a fully interactive earth system model, including data assimilation, so that atmospheric water cycle dynamics can be studied in a unified modeling and observational framework. Currently, the use of Multi-Model Framework (MMF), including the embedding of cloud-resolving models in global general circulation models, is being pursued. This research also calls for the organization and coordination of field campaigns for aerosol and water cycle measurements in conjunction with GEWEX, Climate Variability and Predictability Programme (CLIVAR), and other WCRP international programs on aerosols and water cycle studies. Laboratory scientists have played key roles in major international research projects such as the Joint Aerosol Monsoon Experiment (JAMEX), a core element of the Asian Monsoon Years (2008-2012) under the World Climate Research Program (WCRP), involving both field observations, satellite data utilization and modeling effects. For more information, contact William Lau (William.K.Lau@nasa.gov), Christina Hsu (Christina.Hsu@nasa.gov), Mian Chin (Mian.Chin@nasa.gov), Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov), Eric Wilcox (Eric.Wilcox@nasa.gov) or W.K. Tao (Wei-Kuo.Tao-1@nasa.gov).

4.4.2 Atmospheric Hydrologic Processes and Climate

One of the main thrusts in climate research in the Laboratory is to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the anthropogenic global-change signal. Climate diagnostic studies use a combination of remote sensing and historical climate data, model output, and assimilated data. Diagnostic studies are combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include ENSO, monsoon variability, intraseasonal oscillation, air-sea interaction, and water vapor and cloud feedback processes. Recently, the possible impact of anthropogenic aerosol on regional and global atmospheric water cycles has been included. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, nonlinear system analysis, and satellite orbit-related sampling calculations are used. Maximizing the use of satellite data for better interpretation, sampling, modeling, and eventually prediction of geophysical and hydroclimate systems is a top priority of research in the Laboratory. Laboratory scientists are also engaged in research involving effects of Saharan dust on hurricanes and possible linkage between tropical cyclones and global warming.

Satellite-derived data sets for key hydroclimate variables such as rainfall, water vapor, clouds, surface wind, sea surface temperature, sea level heights, and land surface characteristics are obtained from a number of different projects: MODIS, AMSR, TRMM, the Quick Scatterometer Satellite (QuikSCAT) and Topography Experiment (TOPEX)/Poseidon, the Earth Radiation Budget Experiment (ERBE), Clouds and the Earth's Radiant Energy System (CERES), the International Satellite Cloud Climatology Project (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), the Atmospheric Infrared Sounder (AIRS), TOMS, Special Sensor Microwave Imager (SSM/I), MSU, and TOVS Pathfinder. Diagnostic and modeling studies of diurnal and seasonal cycles of various geophysical parameters are being conducted using satellite data to validate climate model output, and to improve physical parameterization in models. For more information, contact William Lau (William.K.Lau@nasa.gov), Tom Bell (Thomas.L.Bell@nasa.gov), or Yogesh Sud (Yogesh.C.Sud@nasa.gov).

4.4.3 Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the AMSR on EOS Aqua (AMSR-E).

The retrieval techniques include the following:

- A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations for improved estimations.

- An empirical relationship that relates cloud thickness, humidity, and other parameters to rain rates, using TOVS and Aqua–AIRS sounding retrievals.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, diurnal variation of precipitation over both land and ocean, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.4.4 Rain Measurement Validation for TRMM

The objective of the TRMM Ground Validation Program is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the GES DISC. With these products, the validity of TRMM measurements is being established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.5 Modeling

Modeling is an important aspect of our research, and is the path to understanding the physics and chemistry of our environment. Models are intimately connected with the data measured by our instruments: models are used to interpret data, and the data is combined with models in data assimilation. Some of our modeling activities are highlighted below.

4.5.1 50-Year Chemical Transport Model (CTM) Output

A 50-year simulation of stratospheric constituent evolution was completed using the Code 613.3 three-dimensional (3-D) chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N_2O appropriate for the period 1973–2023. Sulfate aerosols were also specified, and represent the eruptions of El Chichón and Mt. Pinatubo. Simulations with constant chlorine (1979 source gases) and low chlorine (1970 levels) and without the volcanic aerosols have also been completed to help distinguish chemical effects from effects of both interannual variability and a trend in the residual circulation in the input meteorological fields. The model output from all simulations is available on the Code 613.3 science system; software to read the output is also available. Although the CTM itself is run at $2° \times 2.5°$ latitude/longitude horizontal resolution; the output is stored at $4° \times 5°$ latitude/longitude. Higher resolution files are available from UniTree, the Code 606.2 archive. The model output stored on the science system is for six days each month; daily fields are saved on UniTree. Details about this and other CTM simulations are available from the Code 613.3 Web site at http://code916.gsfc.nasa.gov/Public/Modelling/3D/exp.html, which provides information about the various simulations.

Output from the three-dimensional Chemistry and General Circulation Model (CGCM) is also available on the Code 613.3 science system. Like the CTM simulations, these include boundary conditions that are specified for various trace gases. The simulations use either observations or model results for the ocean temperatures. Readers for this output, a description of the files that are available, and some details of the simulations are found on http://hyperion.gsfc.nasa.gov/Personnel/people/Frith/webdir/GEOSCCM/gcm_data_transfer.html. Questions or comments should be addressed to Anne Douglass (Anne.R.Douglass@nasa.gov).

4.5.2 Aerosol Modeling

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. Aerosol is also a key component determining air quality. The Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, developed by researchers in the Laboratory in collaboration with the Global Modeling and Assimilation Office (GMAO, Code 610.1), has been used in a wide range of scientific investigations on aerosol related research by many groups worldwide. The research topics include:

- Satellite data analysis
- Intercontinental transport of atmospheric pollutants
- Aerosol effects on precipitation and clouds
- Aerosol effects on climate forcing
- Aerosol effects on surface air quality
- Atmospheric chemistry and climate interactions
- Inverse modeling of aerosol sources

Furthermore, the GOCART aerosol modules, to expand their modeling and application capabilities, have been implemented in several modeling frameworks. For example, the aerosol simulation capability developed in the GMAO GEOS General Circulation Model has made it feasible to use the aerosol forecast to support field experiments, such as the Tropical Composition, Cloud, and Climate Coupling (TC4) campaign in summer 2007. GOCART has also been incorporated into the Global Modeling Initiative (GMI) modeling framework to interface with multiple meteorological fields for a better understanding of the model uncertainties and for coupling with chemistry simulations. Recently, the NOAA NCEP/NWS has started to adapt the GOCART modules for improving their weather and climate predictions and air quality forecasts.

For more information on aerosol modeling contact Mian Chin (Mian.Chin@nasa.gov), Thomas Diehl (Thomas.Diehl@nasa.gov), Peter Colarco (Peter.R.Colarco@nasa.gov), Arlindo da Silva (Arlindo.DaSilva@nasa.gov), or Huisheng Bian (Huisheng.Bian-1@nasa.gov).

4.5.3 Chemistry-Climate Modeling (CCM)

This project brings together the atmospheric chemistry and transport modeling of the Atmospheric Chemistry and Dynamics Branch and the General Circulation Model (GCM) development of the GMAO. The initial goal is to understand the role of climate change in determining the future composition of the atmosphere. We have coupled our stratospheric chemistry and transport into the Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms. We have run simulations of the past starting in 1950 and have extended them into the future to the year 2100. These simulations led to the discovery that ozone has increased in the middle stratosphere over the Antarctic during summers of the last two decades. The simulation was confirmed by examining data from the SBUV series of satellites. We are now setting up to run the scenarios being defined for the next ozone assessment using the same chemistry coupled into a new version of the general circulation model, GEOS-5. The GEOS-5 version has now been coupled to the Combined Stratospheric–Tropospheric Model (COMBO) that has been developed under the Global Modeling Initiative (GMI). The GEOS-5/COMBO version of the CCM is being tested and will be used to attack scientific questions concerning the composition of both the troposphere and stratosphere and their interactions with the climate system.

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (Global Modeling and Assimilation Office). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), Steven Pawson (Steven.Pawson-1@nasa.gov), or Anne Douglass (Anne.R.Douglass@nasa.gov).

4.5.4 Cloud and Mesoscale Modeling (Multi-scale Modeling)

Three different coupled modeling systems were again improved over the last year. These models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones, hurricanes, winter storms, cold rain-bands, tropical and mid-latitude deep convective systems, surface (i.e., ocean and land, vegetation and soil) effects on atmospheric convection, cloud–chemistry, cloud–aerosol, and stratospheric–tropospheric interactions. Other important applications include long-term integrations of the models that allow for the study of transport, air–sea, cloud–aerosol, cloud-chemistry, and cloud–radiation interactions and their role in cloud–climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy, precipitation efficiency, radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical, and mid-latitude weather systems.

In the first modeling system, the NASA Goddard finite volume GCM (fvGCM) is coupled to the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model). he fvGCM allows for global coverage, and the GCE model allows for explicit simulation of cloud processes and their interactions with radiation and surface processes. This modeling system has been applied and its performance tested for two different climate scenarios, El Niño (1998) and La Niña (1999), for the diurnal variation of precipitation processes, and for flood/drought events during three different years (2005–2007). The new, coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intra-seasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs. In addition, the fvGCM is being used to conduct very high-resolution simulations (global mesoscale modeling) to model the tropical cyclone formation and the Madden-Julian Oscillation (MJO). Preliminary results for five tropical cyclones indicate that the high-resolution global model is capable of predicting their genesis about two to three days in advance as well as predicting their subsequent movements.

The second modeling system couples various NASA Goddard physical packages (i.e., microphysics, radiation, and a land surface model) into the next generation weather forecast model known as the Weather Research and Forecasting (WRF) model. WRF is being developed at NCAR by a consortium of Government entities for research applications by the scientific community, and ultimately as the basis for a future operational forecast model at the National Center for Environmental Prediction (NCEP). This coupled modeling system allows for better forecasts (or simulations) of convective systems in Oklahoma, snow events in Canada, severe weather in Taiwan, monsoons in India, and hurricanes in the Atlantic. The WRF is being improved to provide real-time forecasting for NASA field campaigns. This real-time system could give better guidance on flight missions for NASA aircraft.

The third modeling system is the improved GCE model, which has been developed and improved at Goddard over the last two decades. The GCE model has recently been improved in its abilities to simulate the impact of atmospheric aerosol concentration on precipitation processes and the impact of land and ocean surfaces on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate satellite-observed brightness temperatures at different frequencies. This new coupled model system allows us to better understand cloud and precipitation processes in the Tropics as well as snow events at higher latitudes and to improve both precipitation retrievals from NASA satellites and the representation of moist processes in global and climate models. Figure 4.13 shows a schematic of the Goddard multi-scale modeling systems.

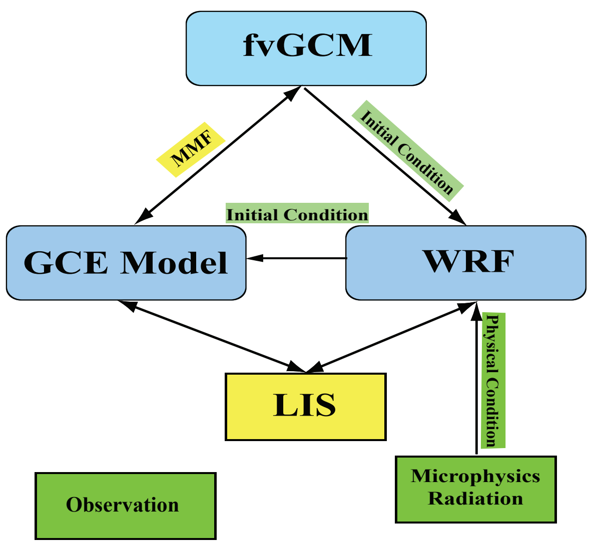


Figure 4.13 Goddard Multi-scale Modeling Systems. The coupling between the fvGCM and GCE is two-way [termed a multi-scale modeling framework (MMF) or super-parameterization], while the coupling between the fvGCM and WRF, and WRF and the GCE is only one-way. LIS is the land information system developed in the Goddard Hydrological Sciences Branch (Code 614.3). LIS has been coupled interactively with both WRF and GCE. Additionally, WRF has been enhanced by the addition of several of the GCE model's physical packages (i.e., microphysical scheme with four different options and short- and long-wave radiative transfer processes with explicit cloud-radiation interactive processes). Observations play a very important role in providing data sets for model initialization and validation, and consequently improvements.

In addition, a cloud library that consists of clouds and cloud systems that developed in different geographic locations is being generated and posted on a Goddard Web site for the public. The cloud data is being used for improving the performance of GPM snow retrievals, for improving the representation of moist processes in large-scale models, and for improving our understanding of precipitation processes associated with impact weather (i.e., hurricane, monsoon, and severe precipitation events). The Web address for the Goddard cloud library is http://portal.nccs.nasa.gov/cloudlibrary/index2.html.

The same microphysical, long- and shortwave radiative transfer, explicit cloud-radiation, and cloud-surface interactive processes are applied in all three modeling systems (called multi-scale modeling system with unified physics). The results from these modeling systems were compared to physical parameters estimated from NASA EOS satellites (i.e., TRMM, CloudSat, Aqua-MODIS, AMSR-E) in terms of surface rainfall and vertical cloud and precipitation structures. In addition, simulated physical parameters (i.e., condensates or hydrometeors, temperature, and humidity profiles) from the Multi-scale Modeling can be used to simulate top-of-atmosphere radiance and backscattering profiles consistent to the NASA EOS satellite measurements through the end-to-end NASA Goddard Earth Satellite Simulator. This permits a) better evaluation of the Goddard physical packages by comparing model results with direct EOS satellite measurements and b) support for NASA's satellite missions (e.g., A-Train, TRMM and GPM) by providing virtual satellite measurements as well as simulated atmospheric environments as an a priori database of physically-based precipitation retrieval algorithms. The model results were also compared to NASA and non-NASA field campaigns.

The scientific output from the modeling activities was again exceptional in 2007 with more than 10 new papers published, in press or accepted. For more information, contact Wei-Kuo Tao (Wei-Kuo.Tao-1@nasa.gov).

4.5.5 Global Modeling Initiative (GMI)

The GMI was initiated under the auspices of the Atmospheric Effects of Aviation Program in 1995. The goal of GMI is to develop and maintain a state-of-the-art modular 3-D chemical transport model (CTM), which can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including, but not limited to, the effect of aircraft. The GMI model also serves as a testbed for model improvements. The goals of the GMI effort follow:

- reduce uncertainties in model results and predictions by understanding the processes that contribute most to the variability of model results, and by evaluating model results against existing observations of atmospheric composition;
- understand the coupling between atmospheric composition and climate through coordination with climate models; and
- contribute to the assessment of the anthropogenic perturbations to the Earth system.

The different components of the GMI model have been recoded for compliance with the Earth Science Modeling Framework. The GMI model is being evaluated through comparison to satellite, aircraft, and ground-based measurements. The Combined Stratospheric-Tropospheric Model (COMBO), has been very successful in simulating the temporal and spatial distribution of ozone measured by Aura instruments, both in the stratosphere and upper troposphere. A "tape recorder" effect in CO measurements from MLS is reproduced by the model. This "tape recorder" is driven by the seasonality of biomass burning. The model has also compared well with tropospheric ozone columns derived from OMI and MLS measurements, and with CO from the AIRS instrument. Comparison to OMI tropospheric column of NO_2, as well as to surface ozone measurements over Europe also show good agreement. Further testing with satellite data, aircraft, and ground-based measurements are also underway.

The GMI model has participated in the assessment carried out by the Hemispheric Transport of Atmospheric Pollutants (HTAP) international effort. Results of the model have been incorporated in the HTAP interim report, and will contribute to several scientific publications. For more information, contact Jose Rodriguez (Jose.M.Rodriguez@nasa.gov).

4.5.6 Cloud Radiation Parameterization in Atmospheric GCM

The main stumbling block in climate evaluations with a General Circulation Model (GCM) is due to the inability of the GCM to simulate realistic climate change. Better accuracy of the sub-models of physical processes (commonly called physical parameterizations) is vital to improving simulations. Thus, more subtle unsolved problems require more accurate models that simulate smaller biases; this implies more attention to physical processes that were previously ignored or poorly represented. The cloud parameterizations are among the primary hurdles. We use the Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme (McRAS), an in-house developed prognostic cloud-scale dynamics and cloud water substance scheme. McRAS includes representation of source and sink terms of cloud-scale condensation, microphysics of precipitation and evaporation, as well as horizontal and vertical advection of cloud water substance. It tries to capture physical attributes of cloud life cycles, effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity effects for radiative transfers. Most of these are based on algorithms developed by Laboratory scientists.

Whereas the GMAO has the overall responsibility for developing basic state-of-the-art climate models that are bias free; nevertheless, cloud-physics and aerosol-cloud-radiation interaction issues are among the primary interests of several scientists of the Goddard Laboratory for Atmospheres. New parameterizations are being developed for internally and externally mixed aerosols interacting with clouds. Since activated aerosols nucleate clouds as well as determine the number of cloud drops, at inception, aerosols species, mass concentrations and size distributions are central to cloud optical properties and precipitation microphysics. We have instituted a version of the Nenes and Seinfield aerosol-nucleation scheme for water clouds. The ice–cloud processes are much more complex; some of them are not well understood; however, empirical relations from satellite and other *in situ* field measurements help to bridge the gap. Active research is in progress to make fundamental advances in this area. We have implemented the Liu and Penner ice nucleation parameterization. The total aerosol–cloud interaction complex, called McRAS-AC, is an upgrade to McRAS. Laboratory scientists are evaluating all aspects of the aerosol cloud and precipitation processes that include cloud optical properties, precipitation intensity, and cloud drop/particle size distribution, as well as validation of model simulations against *in situ* and satellite data.

For atmospheric radiation, we have developed efficient, more accurate, and modular longwave and shortwave radiation codes with parameterized direct effects of man-made and natural aerosols, and clouds that depend upon aerosol nucleation and precipitation microphysics. The climate model simulates liquid/ice mass, the number and size-distribution of cloud drops whereas the radiation code converts this data into optical properties of clouds. The radiation codes are also upgraded for efficient computation of climate sensitivities to water vapor, cloud optical properties and aerosols to simulate the direct effects of aerosols on shortwave and longwave radiative forcing. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

Our simulation research involves the prognostic cloud-water schemes with aerosol cloud radiative effects using observations from the ARM Cloud and Radiation Test Bed (ARM CART) and Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA COARE) intensive observing periods, as well as satellite data. Biases in the GCM-simulated diurnal cycle of rainfall are large and show widely different characteristics in different regions of the world. TRMM satellite rainfall retrievals also provide the essential validation statistics. We have conducted ensemble simulations for the West African Monsoon Modeling and Evaluation intercomparison project. Preparing the model for the above studies required major upgrades to the existing cloud physics in McRAS, as well as producing aerosol data sets for cloud-aerosol interactions and validation. We have utilized our model for a number of simulation studies that include two 10-year Atmospheric Model Intercomparison Project style simulations for investigating the local and remote influences of sea-surface temperatures on precipitation. Thus, focused model development and evaluations of aerosol-cloud-radiation sub models are the primary thrusts of model upgrades. For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

4.5.7 Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional (2-D and 3-D, respectively) models to understand the behavior of ozone and other atmospheric constituents. We use the 2-D models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects; such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. Three-dimensional stratospheric Chemical Transport Models (CTMs) simulate the evolution of ozone and trace gases that affect ozone. The constituent transport is calculated using meteorological fields (winds and temperatures) generated by the GMAO or using meteorological fields that are output from a GCM. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and multi-annual. The model simulations are compared with observations, with the goal of illuminating the complex chemical and dynamical processes that control the ozone layer, thereby improving our predictive capability. We are participating in an ongoing collaboration with GMAO through which the photochemical calculation of the CTM is combined with a general circulation model; changes in radiatively active gases feedback to the circulation through the radiative code. The chemistry and general circulation model (CGCM) is being used to investigate the impact of trace gases changes on ozone and climate on long time scales (multi-decadal to century).

The modeling effort has evolved in the following directions:

1. Lagrangian models are used to calculate the chemical evolution of an air parcel along a trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations.

2. Two-dimensional noninteractive models have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multi-decadal chemical assessment studies.

3. Two-dimensional interactive models include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes.

4. Three-dimensional CTMs have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport.

5. Three-dimensional CGCMs combine a complete representation of photochemical processes with a general circulation model.

The constituent fields calculated using winds from a new GCM developed jointly by the GMAO and NCAR exhibit many observed features. We are also using output from this GCM in the current CTM for multi-decadal simulations. The CGCM reproduces features in the ozone trends derived from SBUV observations that are not produced by the CTM because they are caused by interaction of ozone changes with the meteorological fields. Through the Global Modeling Initiative, the CTM is being improved by implementation of a chemical mechanism suitable for both the upper troposphere and lower stratosphere. This capability is needed for interpretation of data from EOS Aura, which was launched in July 2004. Within the next two years this combined mechanism will be implemented in the CGCM.

The Branch uses trace gas data from sensors on the Upper Atmosphere Research Satellite (UARS), on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model processes. The integrated effects of processes such as stratosphere-troposphere exchange, not resolved in 2-D or 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov).

4.6 Support for NOAA Operational Satellites

In the preceding sections, we examined the Laboratory for Atmosphere's Research and Development work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's operational remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists ensure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Postdoctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

The Laboratory is supporting the formulation phase for the next generation GOES mission, known as GOES-R, which will supply a hundredfold increase in real-time data. Laboratory scientists are involved in specifying the requirements for the GOES-R advanced imager, high-resolution sounding suite, solar imaging suite, and *in situ* sensors. They participate in writing each Request for Proposal (RFP), serve on each Source Evaluation Board (SEB) for the engineering formulation of these instruments, and review vendors' progress during construction and testing of the instruments. For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

4.6.1 GOES

GSFC project engineering and scientific personnel support NOAA for GOES. GOES supplies images and soundings for monitoring atmospheric processes, such as moisture, winds, clouds, and surface conditions, in real time. GOES observations are used by climate analysts to study the diurnal variability of clouds and rainfall, and to track the movement of water vapor in the upper troposphere. The GOES satellites also carry an infrared multichannel radiometer, which NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States to improve numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images via the World Wide Web (http://goes.gsfc.nasa.gov/). For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

4.6.2 NPOESS

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the SEB as technical advisors. Laboratory personnel were involved in evaluating proposals for the Ozone Mapper and Profiler System (OMPS) and the Crosstrack Infrared Sounder (CrIS), which will accompany the Advanced Technology Microwave Sounder (ATMS), and Advanced Microwave Sounding Unit (AMSU) crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operational Algorithm Team (SOAT) and the Ozone Operational Algorithm Team (OOAT) that will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trial studies involving CrIS and ATMS, the advanced infrared and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of CrIS to determine atmospheric CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2 ppm (0.5%) from CrIS under clear conditions, total CH_4 to 1%, and total CO to 15%. This performance is comparable to what is being obtained from AIRS. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

4.6.3 CrIS for NPP

CrIS is a high-spectral resolution interferometer infrared sounder with capabilities similar to those of AIRS. AIRS was launched with AMSU-A and the Humidity Sounder for Brazil (HSB) on the EOS Aqua platform on May 4, 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. Current results with AIRS/AMSU/HSB data demonstrate that the temperature sounding goals for AIRS, i.e., root mean squared accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, are being met over the ocean. AIRS radiances are now assimilated operationally by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the NOAA/National Center for Environmental Prediction (NCEP). Simulation studies were conducted for the IPO to compare the performance of AIRS/AMSU/HSB with that expected of CrIS/ATMS, and results show comparable performance is expected.

Methodology has been developed and implemented to generate proxy CrIS/ATMS data based on AIRS/AMSU observations. This data is representative of what CrIS/ATMS "would see" given the actual geophysical conditions observed by AIRS/AMSU. We are using this data to test the performance of the Northrop Grumman Space Technology (NGST) prototype operational CrIS/ATMS retrieval algorithm and compare it with a government CrIS/ATMS algorithm modeled after the AIRS Science Team (Joel.Susskind-1@nasa.gov).

4.6.4 Ozone Mapper Profiler Suite (OMPS)

OMPS will become the next U.S. operational ozone sounder to fly on NPOESS. The instrument suite has heritage from TOMS and SBUV for total ozone mapping and ozone profiling. The need for high performance profiles providing better vertical resolution in the lower stratosphere resulted in the addition of a limb scattering profiler to the suite. The limb scattering profiler instrument has heritage from the two Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE) shuttle demonstration flights in 1997 (STS-87) and 2003 (STS-107). These missions were developed by our Laboratory with partial support by the IPO. Data from these experimental flights are being used by Laboratory staff personnel to characterize the OMPS instrument and algorithm. (Note: the limb profiler currently has been de-scoped from NPOESS for cost reduction reasons but may fly on NPP. A final decision is pending.)

Laboratory scientists continue to support the IPO through the OOAT and the NPP mission science team. Laboratory scientists are conducting algorithm research, advising on pre- and post-launch calibration procedures, and providing recommendations for validation. They participate in reviews for the OMPS instrument contractor and the NPOESS system integrator. The Laboratory staff members are also assessing OMPS data for climate research. An algorithm has been developed to analyze the SAGE III data when SAGE III operates in a limb scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE-1 and SOLSE-2 missions. The advanced ultraviolet and visible radiative transfer models developed in the Laboratory over the last two decades enable this research. The two decades of experience in TOMS and SBUV calibration and validation will also be applied to OMPS. For more information, contact Richard McPeters (Richard.D.McPeters@nasa.gov).

4.6.5 Tropospheric Wind Profile Measurements

Measurements of tropospheric wind profiles from ground, air, and spaceborne platforms are important for understanding atmospheric dynamics on a variety of time scales. Numerous studies have shown that direct measurement of global winds will greatly improve numerical weather prediction. Because of this importance, the operational weather forecasting communities have identified global tropospheric winds as the number one unmet measurement requirement in the Integrated Operational Requirements Document (IORD-II) for NPOESS, the next generation polar orbiting weather satellite. The Laboratory is using these requirements to develop new Direct Detection Doppler Lidar technologies and systems to measure tropospheric wind profiles, first from the ground and on high altitude aircraft, and then from satellites. Ground-based (GLOW) and airborne (TWiLiTE) Doppler lidar systems provide critical validation of new technologies proposed for eventual spaceborne operation. ESTO and the NPOESS IPO are supporting the effort. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

4.7 Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers - the project scientist and the project manager - who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Table 4.3 lists the project- and deputy project scientists for current missions; Table 4.4 lists the validation and mission scientists and major participants for various campaigns.

Table 4.3: Laboratory for Atmospheres Project and Deputy Project Scientists.

Project Scientists		Deputy Project Scientists	
Name	Project	Name	Project
Robert Adler	TRMM	Christina Hsu	NPP
Pawan K. Bhartia	OMI	Joanna Joiner	EOS Aura
Robert Cahalan	EOS SORCE	Hans Mayr	AIM
Dennis Chesters	GOES	Steve Platnick	EOS Aqua
James Gleason	NPP	Si-Chee Tsay	EOS Terra
Jay Herman	DSCOVR	Warren Wiscombe	ARM, Chief Scientist

Table 4.4: Laboratory for Atmospheres Validation and Mission Scientists, and Major Participants/Instruments.

EOS Validation Scientist	Field/Aircraft Campaigns		
Name	Mission	Name	Campaign Leaders
David Starr	EOS	Paul Newman	TC4
		Judd Welton	MPLNET
		Name	Campaign/Instrument
		Bojan Bojkov	SAUNA II/Ozonesondes
		Alexander Cede	SAUNA II/Double Brewer
		Rich McPeters	SAUNA II/Double Brewer

		Tom McGee	SAUNA/STROZ-LITE WAVES_2007/AT Raman Lidar MOHAVE II/ATL
		Matt McGill	TC4, CLASIC /CPL
		Gerry Heymsfield	TC4, CLASIC /CRS
		Jay Herman	NO_2 Measurement/PANDORA Spectrometer
		David Whiteman	WAVES_2007/RASL

4.8 Interactions with Other Scientific Groups

4.8.1 The Academic Community

The Laboratory relies on collaboration with university scientists to achieve its goals. Such relationships make optimum use of Government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. A number of Laboratory members teach courses at nearby universities and give lectures and seminars at U.S. and foreign universities. (See Section 6 for more details on the education and outreach activities of our Laboratory.) The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs at universities or other Federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 2, reflects our many scientific interactions with the outside community; over 85% of the publications involve coauthors from institutions outside the Laboratory.

Prime examples of the collaboration between the academic community and the Laboratory are given in this list of collaborative relationships via Memoranda of Understanding or cooperative agreements:

- Cooperative Institute of Meteorological Satellite Studies (CIMSS), with the University of Wisconsin, Madison;
- ESSIC, with the University of Maryland, College Park;
- GEST Center, with the University of Maryland, Baltimore County (and involving Howard University);
- JCET, with the University of Maryland, Baltimore County;
- Joint Center for Observation System Science (JCOSS), with the Scripps Institution of Oceanography, University of California, San Diego; and
- Cooperative agreement with Colorado State University, Fort Collins, Colorado.

These collaborative relationships have been organized to increase scientific interactions between the Laboratory for Atmospheres at GSFC, and the faculty and students at the participating universities.

In addition, university and other outside scientists visit the Laboratory for periods ranging from one day, to as long as three years. Some of these appointments are supported by the NASA Postdoctoral Program administered by the Oak Ridge Associated Universities; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the GEST Center. Visiting Scientists are appointed for up to two years and perform research in pre established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design.

4.8.2 Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA Centers and Federal laboratories. Our ties with the other NASA Centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the Agency's scientific objectives.

Our interactions with other Federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground-truth activities for satellite missions, and operational satellites. An example of interagency interaction is the NASA/NOAA/National Science Foundation (NSF) Joint Center for Satellite Data Assimilation (JCSDA), which is building on prior collaborations between NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

4.8.3 Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts have included the Tropical Rainfall Measuring Mission (TRMM), with the Japanese National Space Development Agency (NASDA); the TOMS program with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the OMI Program with Netherlands's Agency for Aerospace Programs (NIVR); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the Validation of International Satellites and study of Ozone Loss (VINTERSOL) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort, which took place in January 2003. In 2004, another international collaboration started with the upload of instruments for the Polar Aura Validation Experiment (PAVE). PAVE is an Aura satellite validation involving instruments on the DC-8. Many of the experimenters from SOLVE II are involved in this campaign, which took place in late January and early February of 2005. This cooperation continued during 2006 in campaigns such as CR-AVE, INTEX-B, and MILAGRO, and in 2007 in campaigns such as TC4 and others described in Section 4.2

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions, to brief visits for giving seminars or working on joint science papers.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, SBIR projects, and technology transfer activities. Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the MPL, holographic optical scanner technology, and Circle to Point Conversion Detector. New research proposals involving technology development will have strong commercial partnerships wherever possible.